Can a contemporary dietary assessment tool or wearable technology accurately assess the energy intake of professional young rugby league players? A doubly labelled water validation study.

Running Head: 'Can Snap-N-Send or wearable technology accurately assess the energy intake of professional young athletes?'

Word Count: 4,000
Abstract Word Count: 250

Abstract

Accurate quantification of energy intake is imperative in athletes; however traditional dietary assessment tools are frequently inaccurate. Therefore, this study investigated the validity of a contemporary dietary assessment tool or wearable technology to determine the total energy intake (TEI) of professional young athletes.

The TEI of eight professional young male rugby league players was determined by three methods; Snap-N-Send, SenseWear Armbands (SWA) combined with metabolic power and doubly labelled water (DLW; intake-balance method; criterion) across a combined ten-day pre-season and seven-day in-season period. Changes in fasted body mass were recorded, alongside changes in body composition via isotopic dilution and a validated energy density equation. Energy intake was calculated via the intake-balance method.

Snap-N-Send over-reported pre-season and in-season energy intake by 0.21 (2.37) $MJ \cdot day^{-1}$ and 0.51 (1.73) $MJ \cdot day^{-1}$, respectively. This represented a *trivial* and *small* standardised mean bias, and *very large* and *large* typical error. SenseWear Armbands and metabolic power under-reported pre-season and in-season TEI by 3.51 (2.42) $MJ \cdot day^{-1}$ and 2.18 (1.85) $MJ \cdot day^{-1}$, respectively. This represents a *large* and *moderate* standardised mean bias, and *very large* and *very large* typical error. There was a *most likely* larger daily error reported by SWA and metabolic power than Snap-N-Send across pre-season (3.30 (2.45) $MJ \cdot day^{-1}$; ES = 1.26 ±0.68; $p = 0.014$) and in-season periods (1.67 (2.00) $MJ \cdot day^{-1}$; ES = 1.27 ±0.70; $p = 0.012$).

This study demonstrates the enhanced validity of Snap-N-Send for assessing athlete TEI over combined wearable technology, although caution is required when determining the individual TEIs of athletes via Snap-N-Send.

Key words: Total energy intake, validity, sport

Introduction

Accurate quantification of energy intake is imperative within athletic populations, however traditional dietary assessment tools are frequently inaccurate (Capling et al., 2017), outlining a requirement for new and improved practical assessments of diet (Dhurandhar et al., 2015). Total energy intake (TEI) underpins successful manipulation of energy balance (Hall and Guo, 2017), representing overall macronutrient consumption, dictating stores of body tissue (i.e. body mass (BM) and composition) and optimal body function (Thomas et al., 2016). Consequently, the TEI of athletes requires careful periodisation and individualisation across the season (Mountjoy et al., 2018). Unfortunately, the assessment of diet is confounded by considerable random day-to-day variation and systematic over- and under-reporting bias (Beaton et al., 1997), likely exacerbated by the unique dietary practises of athletes (Capling et al., 2017). Such errors result in spurious casual correlations (Archer, 2017), undermining effective dietary assessment and consequential intervention (Costello et al., 2018c). Therefore, to inform more efficacious nutritional practice, practitioners require accurate dietary assessment tools applicable within the time and result pressured environment of high-performance sport.

To address aforementioned limitations, a novel behavioural approach titled Snap-N-Send has recently been validated within a professional young rugby league (RL) population (Costello et al., 2017a). Snap-N-Send utilises contemporary behaviour change science (Behaviour Change Wheel; Michie, Atkins, West; 2014) and innovative smartphone technology to behaviourally adhere participants to real-time dietary assessment in their habitual environment (Costello et al., 2017a, Costello et al., 2017b). Snap-N-Send has been shown to provide improved assessment of athlete TEI at a group level across ecologically and internally valid research environments, reporting enhanced validity over typically employed traditional dietary assessment tools (4-day food diary & 24-hour dietary recall interview; (Costello et al., 2017a). Nevertheless, preliminary results require replication across longer assessment periods before the measurement accuracy of Snap-N-Send can be confirmed.

Despite recent advancements, all forms of dietary self-assessment are likely to introduce some degree of measurement error; consequently, predicting athlete TEI from practically accessible wearable technology and validated mathematical models could potentially represent a superior approach. The validity of the intake-balance method (TEI = total energy expenditure (TEE) + change in energy stores) to estimate the TEI of free-living individuals has recently been established (Hall, 2014). This approach relies upon accurate measurement of athlete BM and body composition change, alongside exact TEE assessment via doubly labelled water (DLW) (Schoeller, 1990). However, the high measurement cost, time and expertise requirement of DLW evidences its unsuitability to determine the daily TEE of athletes. Conversely, practically accessible assessments of TEE such as those provided by isolated or combined wearable technology (metabolic power (Osgnach et al., 2010) & SenseWear Armbands (SWA) (Reeve et al., 2014)), could provide a convenient and potentially accurate method to assess the TEI of athletes within everyday applied practise.

Therefore, this study had two primary aims: (i) determine the validity of Snap-N-Send and (ii) combined SenseWear Pro3 Armbands and metabolic power to assess the TEI of professional young RL players across a pre-season and in-season period. Both methods were validated against TEI determined via the literature gold standard, DLW (Westerterp, 2017), and the intake-balance method (Schoeller, 2009, Hall, 2014).

Methods

Design

This study took place over two distinct time points within the same playing season, consisting of two separate five-day periods that were combined across a pre-season (Monday-Friday; (Costello et al., 2018a)) and a consecutive seven-day in-season assessment period

(Thursday-Wednesday; Costello et al., *under review*). Across both periods, criterion TEI was determined via the literature gold standard DLW, to measure TEE, and the intake-balance method (Hall, 2008, Schoeller, 2009). Practical measures of TEI were self-reported via Snap-N-Send and calculated from practical SWA and metabolic power derived TEE, also via the intake-balance method.

Participants

A total of eight healthy, professional young male RL players were recruited, including six participants for the pre-season period and seven participants for the in-season period. Five of the same participants were recruited across both periods. Participant characteristics were (mean (standard deviation); SD) age; 17 (1) years, height; 179.5 (8.7) cm, BM; 90.5 (11.4) kg. Participants were chosen from a range of playing positions including Loose Forward, Prop Forward (x2), Half Back, Hooker, Full Back, Back Row and Wing. Prior to volunteering, all participants signed a written statement of consent. Ethics approval was granted by the Research Ethics Committee (Leeds Beckett University, UK).

Criterion Total Energy Intake - Doubly Labelled Water

The DLW method measures the disappearance rates of two known stable isotopes (^{18}O & ^{2}H), determining carbon dioxide production and subsequent TEE (Weir, 1949). Doubly labelled water is the literature gold standard assessment of TEE within free-living environments (Westerterp, 2017), with an established accuracy of 1-2 % and precision of ~5-7 % (Schoeller and Webb, 1984). As such, criterion TEI was established via DLW assessed TEE and the intake-balance method across both assessment periods (Hall, 2008, Schoeller, 2009).

Stable Isotope Doses

Doubly labelled water bolus doses consisting of deuterium (^2H) and oxygen (^{18}O) stable isotopes were prepared for each participant in three stages, as has previously been described (Costello et al., 2018b). Doses were calculated relative to the largest BM of any participant included in the study (Schoeller et al., 1980). This included ^2H_2O (99 atom %) and $H_2{}^{18}O$ (10 atom %) based on 0.14 $g \cdot kg^{-1}$ and 0.90 $g \cdot kg^{-1}$ of BM, respectively.

DLW Administration, Urine Collections and IRMS Analyses of Urine Samples

Each dose was provided one day prior to the start of the assessment period (Costello et al., 2018b). A baseline urine sample was provided before oral consumption of a single bolus of DLW ($^2H_2{}^{18}O$), made under close supervision. To ensure consumption of the whole bolus, the dose bottles were washed twice with additional water that participants also consumed. Baseline enrichment was determined from a later urine sample provided by participants at 22:00, allowing for total body water (TBW) equilibrium (Schoeller et al., 1980).

Participants provided daily urine samples at 22:00 across both data collection periods. Samples were collected directly into two date, time and participant ID registered 5 mL cryovials,which were then filtered in compliance with the Human Tissue Act and frozen prior to later laboratory analysis. Analysis of urine samples for ^2H and ^{18}O abundance was performed following gas exchange using a HYDRA 20-22 IRMS (SerCon, Crewe UK), as has previously been described (Costello et al., 2018b). All data were imported into a Microsoft Excel template where the calculation of TBW, body composition, TEE and quality control parameters could be performed.

Total Body Water, Body Mass, Body Composition and Total Energy Expenditure Calculations

Total body water was calculated from stable isotope dilution spaces, based on the intercept of the elimination plot of deuterium (AGENCY, 2011). The tracer elimination rates and subsequent isotope enrichments were specifically calculated from baseline tracer abundance for the assessment periods. Total energy expenditure was then specifically calculated from the stable isotope elimination rate constants and "pool space" (AGENCY, 2011). Throughout the study, tracer enrichment in body water remained above the minimum recommendation (Davidsson, 2009). The Pearson product moment correlation of the tracer elimination plots was greater than 0.99 in all cases. A respiratory quotient of 0.85 was assumed (Schoeller and van Santen, 1982).

Labelled water (i.e. isotope dilution) can also be accurately utilised to measure body composition (Westerterp, 2017), via a two-compartmental model of body composition assessment including fat-free mass (FFM) and fat mass (FM). The hydration of FFM in healthy participants is relatively constant, stabilising at 73% during adulthood (Fomon et al., 1982). Therefore, FFM (kg) can be accurately determined from labelled TBW measurement (kg) divided by a hydration coefficient (Schoeller et al., 1980);

$$FFM = \frac{TBW}{73.2} \quad \text{(Davidsson, 2009) (1)}$$

Fat mass (kg) was then calculated as the difference between BM (kg) and FFM (kg). Body mass was assessed at the start and end of both dietary assessment periods, upon arrival to the club training ground in the fasted state to the nearest 0.1 kg on the same calibrated weighing scales (SECA Mod 220, SECA GMBH & Co. Germany). For the combined ten-day pre-season dietary assessment period, BM change was combined across both five-day assessment periods. For the seven-day in-season dietary assessment period, body mass change was observed.

Isotope dilution measurement of TBW is one of only two available *in vivo* body composition assessment techniques, with assumptions determined from direct carcass analysis, therefore represents a valid body composition approach (Westerterp, 2017). The change in participant body composition across both assessment periods was then estimated from the following validated equation;

$$\frac{\Delta \mathrm{L}}{\Delta \mathrm{BW}} = 1 + \frac{\mathrm{Fi}}{\Delta \mathrm{BW}} - \frac{10.4}{\Delta \mathrm{BW}} W\{\frac{1}{10.4} \exp\left(\frac{\Delta \mathrm{BW}}{10.4}\right) \mathrm{Fi}\exp\left(\frac{\mathrm{Fi}}{10.4}\right)\} \text{ (Hall, 2008) (2)}$$

Specifically, this equation determines lean mass change, from which FM (kg) was calculated as the difference between fasted BM (kg) and estimated FFM (kg) change. ΔL represents the change in lean mass (kg), ΔBW represents the change in BM (kg), Fi represents initial FM (kg) and *W* represents the Lambert W function (Hall, 2008).

Total Energy Intake – Intake-Balance Method

The intake-balance method is based upon the first law of thermodynamics, which states that *energy can be neither created nor destroyed*; thus, for any system, the following equation holds true;

$$Energy\ in = energy\ out + change\ in\ energy\ stores \quad (3)$$

Energy input refers to the chemical energy entering the body from food and drink that can be liberated via metabolism, hence is measured as metabolizable energy (Schoeller, 2009). Energy output is the heat released by the body through established TEE components (resting metabolic rate, RMR; thermic effect of food; & physical activity; (Westerterp, 2007)). Change in energy stores signifies changes in chemical energy that are stored either as fat, glycogen and/or protein (Schoeller, 2009). When TEI does not meet or exceeds energy requirements, the subsequent deficit or surplus is accounted for by metabolism of stored energy (i.e. fat, protein, glycogen). Consequently, the TEI of an individual is equal to TEE when that individual is BM and composition stable; or TEE minus the change in body energy stores (Hall, 2014), thus can be accurately determined from the intake-balance equation (Schoeller, 2009).

In this study, the energy density of lean and FM change was assumed to be 7.6 MJ/kg and 39.5 MJ/kg, respectively, based on the validated work of Hall et al. (2008). Because glycogen constitutes such a small fraction of lean mass, its loss was assumed to be negligible (Wishnofsky, 1958). The metabolizable energy density of BM change (MJ/kg) was then calculated via the following equation;

$$\frac{\Delta E}{\Delta BW} = Pf + (Pl - Pf)\frac{\Delta L}{\Delta BW} \quad \text{(Hall, 2007) (4)}$$

Specifically, ΔE represents change in energy stores, P_f represents energy density of FM change (MJ/kg) and P_l represents energy density of lean mass change (MJ/kg). Consequently, change in energy stores was determined. As a result, two of the energy balance equation variables were known (i.e. TEE and change in energy stores), allowing for TEI to be mathematically calculated via the intake-balance method (Hall, 2008, Schoeller, 2009). Specifically, this was determined from DLW assessed TEE, the criterion TEI (Westerterp, 2017), and SWA and metabolic power assessed TEE across both assessment periods.

Total Energy Intake – Snap-N-Send

Preliminary Workshops

Prior to either assessment, participants attended a preliminary workshop where they were verbally, visually and kinaesthetically taught how to use 'Snap-N-Send'. The method was explained in detail and demonstrated across a number of potentially difficult recording scenarios ('if-then' situations, i.e. periods with limited smartphone or Wi-Fi access). All participants had to individually demonstrate recording competence before the workshop was completed. Population-specific behaviour change techniques (BCTs), designed and implemented via the Behaviour Change Wheel (Michie, Atkins, West; 2014), were applied across the preliminary workshop and assessment period to behaviourally adhere participants to real-time assessment protocols. Detailed explanation of 'Snap-N-Send' or the BCTs employed throughout the preliminary workshop has previously been reported (Costello et al., 2017a).

Pre-Season & In-Season Assessment Periods

'Snap-N-Send' requires participants to take two pictures of every food or fluid item consumed on a smartphone, which are then sent immediately to the researcher via a free cellular picture messaging smartphone application (WhatsApp)(Costello et al., 2017a). The first picture is taken prior to consumption and details what the participant intends to consume, whereas the second picture is taken immediately after consumption identifying what the participant actually ingested. A picture is still required even if an item is consumed in its entirety. Finally, using text or voice recording participants detail pictures with item brand labels, weights (i.e. participant weighed or from label packaging), cooking methods and a clear description of all the items contained in each picture. Once received, the lead researcher immediately checks that picture and description quality are suitable for accurate analysis. If unsatisfactory, participants are immediately contacted via WhatsApp asking for further or more detailed clarification (Costello et al., 2017a).

Throughout both assessment periods, contemporary behaviour change science (Behaviour Change Wheel; Michie, Atkins & West., 2014) was utilised to identify and then address participant-specific barriers to real-time dietary assessment (Costello et al., 2017b). For example, participant motivation to behaviourally adhere to real-time assessment protocols was targeted by personalised messages sent over the cellular network (Martin et al., 2012), reminding them of the importance and expectations associated with correct dietary assessment via Snap-N-Send. Messages nudged participants to record around typical meal and snack times (Martin et al., 2012), with additional reminders sent for how to handle difficult potential 'if-then' situations before they occurred. If participants made no contact over three waking hours they were contacted and asked to detail their next intended time of consumption. Participants were encouraged and verbally rewarded for precision, accuracy and adherence throughout both assessment periods; significant figures (i.e. head and assistant coaches; head of athletic development) within the club used smartphone messages and face-to-face contact to congratulate participants who displayed especially impressive methodological commitment. Throughout, participants were reminded to not change their habitual diet and report everything that they consumed. Finally, participants were provided with weighing scales to weigh home-prepared items if required.

Total Energy Intake Analysis

Total energy intakes were analysed by a SENr accredited nutritionist with applied experience within the investigated population. When required, portions of food were matched to pictures provided via 'Snap-N-Send' before being entered for analysis. Energy intakes were determined from Nutritics dietary analysis software (Nutritics 3.06, Ireland), with items not available on the database manually entered from label packaging.

Total Energy Intake – SenseWear Pro3 Armbands & Metabolic Power

Across both assessment periods, the TEE of participants was determined by SWA combined with metabolic power derived from microtechnology units, which was converted into an estimated TEI via the intake-balance method (Hall, 2008, Schoeller, 2009).

SenseWear Pro3 Armbands

The SWA (BodyMedia) were placed on the back of the left triceps of participants via a velcro band, as per manufacturer instructions (Andre et al., 2006). Energy expenditure was calculated in one-minute epochs via the latest proprietary algorithm (v5.2) on the latest SenseWear Innerview Research Software (v8.0, Pittsburgh, USA).

Across both assessment periods, participants wore SWA at all times excluding field-training, periods submerged in water (i.e. showers & baths) and match-play. SenseWear Pro3 Armband values were considered incomplete if worn for less than 95% of either assessment duration outside of time spent in training or competitive match-play. This did not occur across either the pre-season (98 ± 2.1%) or in-season (97.1 ± 1.3%) assessment period. This research protocol was chosen to protect participants and SWA equipment from injury or damage (i.e. collisions or water) and has high ecological validity within professional collision sports (Walker et al., 2016).

Microtechnology Units

Microtechnology units house a global positioning system (GPS) and triaxial accelerometer sampling at 10 and 100 Hz, respectively, alongside a gyroscope and magnetometer (Optimeye S5, Catapult Innovations, Melbourne, Australia). Units were securely positioned between the scapulae of participants using a custom-made vest and worn during all field sessions and competitive match play across both assessment periods; therefore, assessing the expenditure of participants when SWA were removed. Participants utilised the same microtechnology unit across pre-season and in-season data collection periods to eliminate inter-device variability (Akenhead et al., 2014).

All units were turned on prior to field session or match warm-ups and turned off immediately following session or match completion. Data was then downloaded, trimmed and analysed to provide metabolic energy ($kcal \cdot kg^{-1}$) based on metabolic power equations (Osgnach et al., 2010), using Catapult Sprint software [Catapult Innovations, Melbourne, Australia; pre-season number of satellites, version 5.1.7, 15 (3); horizontal dilution of precision 0.8 (0.6); in-season number of satellites, version 5.1.7, 11.9 (2.3); horizontal dilution of precision 0.8 (0.1)].

Statistical Analyses

Raw data are presented as mean (SD). Agreement between practical (Snap-N-Send; SWA & metabolic power) and criterion (DLW) measures of TEI were determined with 90% confidence limits, using an excel spreadsheet (2016, Seattle, USA) to calculate mean bias and typical error of the estimate (Hopkins, 2015). Method comparisons were assessed via magnitude-based inferences and paired t-tests, which were run in R Studio (v 1.414). All mathematical calculations were also run in R Studio (v 1.414). Before statistical analysis, all data were first log-transformed to reduce bias arising from non-uniformity error.

The standardised mean bias was assessed as *trivial* (<0.20), *small* (0.2 to 0.6), *moderate* (0.6 to 1.2), *large* (1.2 to 2.0), *very large* (2.0 to 4.0) or *extremely large* (>4.0). The standardised typical error was assessed as *trivial* (<0.1), *small* (0.1 to 0.3), *moderate* (0.3 to 0.6), *large* (0.6 to 1.0), *very large* (1.0 to 2.0) or *extremely large* (>2.0) (Hopkins, 2015). The magnitude of correlation was assessed as *trivial* (<0.1), *small* (0.1 to 0.29), *moderate* (0.3 to 0.49), *large* (0.5 to 0.69), *very large* (0.7 to 0.89), *nearly perfect* (0.9 to 0.99) or *perfect* (>0.99) (Hopkins, 2015). For null-hypothesis significance testing, statistical significance was assumed at 5% ($P < 0.05$).

Results

Snap-N-Send

Snap-N-Send non-significantly over-reported pre-season and in-season criterion TEI by 0.21 ±2.37 (p=0.833) and 0.51 ±1.73 $MJ \cdot day^{-1}$ (p=0.464), respectively (Table 1). This represents a *trivial* and *small* standardised mean bias and a *very large* and *large* typical error of the estimate, respectively.

SenseWear Pro3 Armbands & Metabolic Power

SenseWear Pro3 Armbands and metabolic power significantly under-reported pre-season and in-season criterion TEI by 3.51 ±2.42 and 2.18 ±1.85 $MJ \cdot day^{-1}$, respectively (Table 1). This represents a *large* and *moderate* standardised mean bias and a *very large* and *very large* typical error of the estimate, respectively.

INSERT TABLE 1 ABOUT HERE

Method Comparison

Across the pre-season period, there was a significant *most likely* larger (3.30 ±2.45 MJ·day^{-1}; ES = 1.26 ±0.68; p = 0.014) daily TEI error reported by SWA and metabolic power (3.51 ±2.42 MJ·day^{-1}) compared with Snap-N-Send (0.21 ±2.37 MJ·day^{-1}). Across the in-season period, there was a significant *most likely* larger (1.67 ±2.00 MJ·day^{-1}; ES = 1.27 ±0.70; p = 0.012) daily TEI error reported by SWA and metabolic power (2.18 ±1.85 MJ·day^{-1}) compared with Snap-N-Send (0.51 ±1.73 MJ·day^{-1}).

Discussion

This study represents the first investigation of Snap-N-Send or combined wearable technology to determine the TEI of professional young RL players across different stages of the season. The results evidence the validity of Snap-N-Send at a group level, while highlighting the relative invalidity of SWA combined with metabolic power at a group and individual level. Despite displaying enhanced relative validity over combined wearable technology and traditional dietary assessment tools validated within athletic populations, Snap-N-Send displayed large random error, illustrating reduced measurement accuracy at an individual level. Consequently, practitioners are encouraged to exercise caution when determining the individual TEI of athletes via Snap-N-Send.

Snap-N-Send displayed a *trivial* and *small* systematic bias and a *very large* and *large* typical error across assessment periods, demonstrating high TEI measurement accuracy at a group level, but poor measurement accuracy at an individual level within a professional young RL cohort. Snap-N-Send over-reported criterion TEI by a 51 (566) $kcal \cdot day^{-1}$ & 121 (413) $kcal \cdot day^{-1}$ across a pre-season and in-season period, respectively, demonstrating high measurement accuracy at a group level within a challenging cohort of adolescent athletes consuming 3,570-3,945 $kcal \cdot day^{-1}$. Results evidence the enhanced relative validity of Snap-N-Send over traditional dietary assessment tools (i.e. food diaries), which have been shown to under-estimated DLW assessed TEE by -667 ((271) $kcal \cdot day^{-1}$ (Capling et al., 2017). However, Snap-N-Send displayed wide within-subject SD, illustrating poor measurement accuracy at an individual level; potentially affecting the applicability of Snap-N-Send within high-performance sport where accurate assessment of individual athletes TEI is prioritised. Such findings could represent varying adherence to real-time dietary recording across participants, illustrating that participants were not behaviourally adhered throughout the entire dietary recording process (Costello et al., 2017b). Nevertheless, results confirm Snap-N-Send as a leading dietary self-assessment tool within sports nutrition literature, outperforming other traditional approaches often utilised within applied practise and research (Rollo et al., 2016, Capling et al., 2017).

Combined SWA and metabolic power displayed a *large* and *moderate* standardised mean bias and a *very large* typical error, illustrating low TEI measurement accuracy across at a group and individual level across both assessment periods. SenseWear Pro3 Armbands and metabolic power significantly under-reported criterion TEI by 838 (578) $kcal \cdot day^{-1}$ and 520 (441) $kcal \cdot day^{-1}$ across a pre-season and in-season period, respectively, illustrating poor measurement error at a group and individual level within a professional young RL cohort. Interestingly, findings are in direct opposition to those recently published within a large cohort of healthy young adults (n= 195), where SWA alone accurately reported TEI via the intake-balance method to within 2 $kcal \cdot day^{-1}$ of DLW (Shook et al., 2018). These results are surprising considering the low measurement accuracy commonly reported for SWA (Santos-Lozano et al., 2017), although the non-athletic population investigated were unlikely to perform high intensity activities common of athletic populations where the measurement accuracy of SWA is typically confounded (Koehler and Drenowatz, 2017).

SenseWear Pro3 Armbands and metabolic power reported a *most likely* larger daily TEI error than Snap-N-Send across both assessment periods, highlighting the superiority of Snap-N-Send to assess the TEI of athletes over combined wearable technology. There was a significant 888 (585) $kcal \cdot day^{-1}$ and 642 (477) $kcal \cdot day^{-1}$ difference in daily TEI error reported by Snap-N-Send compared with SWA combined with metabolic power across pre-season and in-season periods, respectively, confirming the superiority of Snap-N-Send to report the TEI of athletes over commonly utilised wearable technology. Such findings are likely influenced by large TEE measurement error reported by SWA (Koehler and Drenowatz, 2017) and metabolic power within athletic populations (Brown et al., 2016). Ultimately, study findings question the use of SWA and metabolic power to accurately estimate the TEI of professional athletes via the intake-balance method.

The limitations of this study require acknowledgement before appropriate conclusions can be drawn. Firstly, this study employees a small sample of professional young RL players, with five participants involved across both assessment periods; highlighting a requirement for replication across larger cohorts, age-groups and sports. As shown within the original validation (Costello et al., 2017a), Snap-N-Send displayed wide within-subject SD, the source of which is unknown; therefore, future research should identify why certain participants under- or over-reported their dietary intake via Snap-N-Send before such error can be realistically attenuated. The lead researcher in this study collected and analysed all dietary assessment data, thus, future research should employ multiple researchers to individually analyse participant dietary intakes to confirm reported value reliability. Total energy intake represents one component of diet, consequently future research should investigate the ability of Snap-N-Send to determine other dietary components of interest e.g. macronutrient or fluid intake. Finally, the continued development of improved practical measures of athlete TEE and mathematical intake-balance models is required, as all forms of self-reported dietary assessment are likely to introduce some form of assessment error or subject bias (Beaton et al., 1997).

In conclusion, this study provides novel insights into the ability of a contemporary dietary assessment tool or combined wearable technology to determine the TEI of professional young RL players. The results highlight the validity of Snap-N-Send at a group level and relative invalidity of SWA combined with metabolic power to determine athlete TEI at a group and individual level. Study conclusions are strengthened by utilisation of DLW, the literature gold standard assessment of free-living TEE, in combination with the intake-balance approach as the study criterion measure of TEI (Westerterp, 2017). Ultimately, when determining the TEI of professional young RL players at a group level practitioners and researchers are encouraged to utilise Snap-N-Send over combined wearable technology; although caution should be exercised when utilising Snap-N-Send to accurately determine the individual TEIs of athletes.

References

Agency, I. A. E. 2011. *Introduction to Body Composition Assessment Using the Deuterium Dilution Technique with Analysis of Urine Samples by Isotope Ratio Mass Spectrometry,* Vienna, International Atomic Energy Agency.

Akenhead, R., French, D., Thompson, K. G. & Hayes, P. R. 2014. The acceleration dependent validity and reliability of 10 Hz GPS. *J Sci Med Sport,* 17**,** 562-6.

Andre, D., Pelletier, R., Farringdon, J., Safier, S., Talbott, W., Stone, R., Vyas, N., Trimble, J., Wolf, D. & Vishnubhatla, S. 2006. The development of the SenseWear® armband, a revolutionary energy assessment device to assess physical activity and lifestyle. *BodyMedia Inc*.

Archer, E. 2017. *The use of implausible data without caveats is misleading*.

Beaton, G. H., Burema, J. & Ritenbaugh, C. 1997. Errors in the interpretation of dietary assessments. *Am J Clin Nutr,* 65**,** 1100s-1107s.

Brown, D. M., Dwyer, D. B., Robertson, S. J. & Gastin, P. B. 2016. Metabolic Power Method: Underestimation of Energy Expenditure in Field-Sport Movements Using a Global Positioning System Tracking System. *Int J Sports Physiol Perform,* 11**,** 1067-1073.

Capling, L., Beck, K., Gifford, J., Slater, G., Flood, V. & O'connor, H. 2017. Validity of Dietary Assessment in Athletes: A Systematic Review. *Nutrients,* 9**,** 1313.

Costello, N., Deighton, K., Dyson, J., Mckenna, J. & Jones, B. 2017a. Snap-N-Send: A valid and reliable method for assessing the energy intake of elite adolescent athletes. *Eur J Sport Sci,* 17**,** 1044-1055.

Costello, N., Deighton, K., Preston, T., Matu, J., Rowe, J. & Jones, B. 2018a. Are professional young rugby league players eating enough? Energy intake, expenditure and balance during a pre-season. *European Journal of Sport Science***,** 1-10.

Costello, N., Deighton, K., Preston, T., Matu, J., Rowe, J., Sawczuk, T., Halkier, M., Read, D. B., Weaving, D. & Jones, B. 2018b. Collision activity during training increases total energy expenditure measured via doubly labelled water. *Eur J Appl Physiol*.

Costello, N., Mckenna, J., Deighton, K. & Jones, B. 2017b. Commentary: Snap-N-Send: A Valid and Reliable Method for Assessing the Energy Intake of Elite Adolescent Athletes. *Frontiers in Nutrition,* 4.

Costello, N., Mckenna, J., Sutton, L., Deighton, K. & Jones, B. 2018c. Case Study: Using Contemporary Behaviour Change Science to Design and Implement an Effective Nutritional Intervention within Professional Rugby League. *International Journal of Sport Nutrition and Exercise Metabolism,* 0**,** 1-16.

Davidsson, L. 2009. *Assessment of Body Composition and Total Energy Expenditure in Humans Using Stable Isotope Techniques*, International Atomic Energy Agency.

Dhurandhar, N. V., Schoeller, D., Brown, A. W., Heymsfield, S. B., Thomas, D., Sorensen, T. I., Speakman, J. R., Jeansonne, M. & Allison, D. B. 2015. Energy balance measurement: when something is not better than nothing. *Int J Obes (Lond),* 39**,** 1109-13.

Fomon, S. J., Haschke, F., Ziegler, E. E. & Nelson, S. E. 1982. Body composition of reference children from birth to age 10 years. *The American Journal of Clinical Nutrition,* 35**,** 1169-1175.

Hall, K. & Guo, J. 2017. *Obesity Energetics: Body Weight Regulation and the Effects of Diet Composition*.

Hall, K. D. 2007. Body fat and fat-free mass inter-relationships: Forbes's theory revisited. *Br J Nutr,* 97**,** 1059-63.

Hall, K. D. 2008. What is the Required Energy Deficit per unit Weight Loss? *International journal of obesity (2005),* 32**,** 573-576.

Hall, K. D. 2014. Estimating human energy intake using mathematical models. *Am J Clin Nutr,* 100**,** 744-5.

Hopkins WG. Spreadsheets for analysis of validity and reliability. Sportscience. 2015;19:36–42.

Koehler, K. & Drenowatz, C. 2017. Monitoring Energy Expenditure Using a Multi-Sensor Device-Applications and Limitations of the SenseWear Armband in Athletic Populations. *Front Physiol,* 8**,** 983.

Labonté, M.-È., Kirkpatrick, S. I., Bell, R. C., Boucher, B. A., Csizmadi, I., Koushik, A., L'abbé, M. R., Massarelli, I., Robson, P. J., Rondeau, I., Shatenstein, B., Subar, A. F. & Lamarche, B. 2016. Dietary assessment is a critical element of health research – Perspective from the Partnership for Advancing Nutritional and Dietary Assessment in Canada. *Applied Physiology, Nutrition, and Metabolism,* 41**,** 1096-1099.

Michie, S., Atkins, L., & West, R. (2014). The behaviour change wheel: A guide to designing interventions (1st ed.). London: Silverback Publishing

Mountjoy, M., Sundgot-Borgen, J. K., Burke, L. M., Ackerman, K. E., Blauwet, C., Constantini, N., Lebrun, C., Lundy, B., Melin, A. K., Meyer, N. L., Sherman, R. T., Tenforde, A. S., Klungland Torstveit, M. & Budgett, R. 2018. IOC consensus statement on relative energy deficiency in sport (RED-S): 2018 update. *British Journal of Sports Medicine*.

Osgnach, C., Poser, S., Bernardini, R., Rinaldo, R. & Di Prampero, P. E. 2010. Energy cost and metabolic power in elite soccer: a new match analysis approach. *Med Sci Sports Exerc,* 42**,** 170-8.
Reeve, M. D., Pumpa, K. L. & Ball, N. 2014. Accuracy of the SenseWear Armband Mini and the BodyMedia FIT in resistance training. *Journal of Science and Medicine in Sport,* 17**,** 630-634.
Rollo, M. E., Williams, R. L., Burrows, T., Kirkpatrick, S. I., Bucher, T. & Collins, C. E. 2016. What Are They Really Eating? A Review on New Approaches to Dietary Intake Assessment and Validation. *Current Nutrition Reports,* 5**,** 307-314.
Santos-Lozano, A., Hernández-Vicente, A., Pérez-Isaac, R., Santín-Medeiros, F., Cristi-Montero, C., Casajús, J. A. & Garatachea, N. 2017. Is the SenseWear Armband accurate enough to quantify and estimate energy expenditure in healthy adults? *Annals of Translational Medicine,* 5**,** 97.
Schoeller, D. A. 1990. How accurate is self-reported dietary energy intake? *Nutr Rev,* 48**,** 373-9.
Schoeller, D. A. 2009. The energy balance equation: looking back and looking forward are two very different views. *Nutr Rev,* 67**,** 249-54.
Schoeller, D. A. & Van Santen, E. 1982. Measurement of energy expenditure in humans by doubly labeled water method. *J Appl Physiol Respir Environ Exerc Physiol,* 53**,** 955-9.
Schoeller, D. A., Van Santen, E., Peterson, D. W., Dietz, W., Jaspan, J. & Klein, P. D. 1980. Total body water measurement in humans with 18O and 2H labeled water. *Am J Clin Nutr,* 33**,** 2686-93.
Schoeller, D. A. & Webb, P. 1984. Five-day comparison of the doubly labeled water method with respiratory gas exchange. *Am J Clin Nutr,* 40**,** 153-8.
Shook, R. P., Hand, G. A., O'connor, D. P., Thomas, D. M., Hurley, T. G., Hébert, J. R., Drenowatz, C., Welk, G. J., Carriquiry, A. L. & Blair, S. N. 2018. Energy Intake Derived from an Energy Balance Equation, Validated Activity Monitors, and Dual X-Ray Absorptiometry Can Provide Acceptable Caloric Intake Data among Young Adults. *The Journal of Nutrition,* 148**,** 490-496.
Thomas, D. T., Erdman, K. A. & Burke, L. M. 2016. American College of Sports Medicine Joint Position Statement. Nutrition and Athletic Performance. *Medicine and science in sports and exercise,* 48**,** 543-568.
Walker, E. J., Mcainch, A. J., Sweeting, A. & Aughey, R. J. 2016. Inertial sensors to estimate the energy expenditure of team-sport athletes. *Journal of Science and Medicine in Sport,* 19**,** 177-181.
Weir, J. B. 1949. New methods for calculating metabolic rate with special reference to protein metabolism. *J Physiol,* 109**,** 1-9.
Westerterp, K. R. 2007. Determinants of energy expenditure and energy balance. *Appetite,* 49**,** 339.
Westerterp, K. R. 2017. Doubly labelled water assessment of energy expenditure: principle, practice, and promise. *European Journal of Applied Physiology,* 117**,** 1277-1285.
Wishnofsky, M. A. X. 1958. Caloric Equivalents of Gained or Lost Weight. *The American Journal of Clinical Nutrition,* 6**,** 542-546.

Table 1. Pre-season & in-season criterion vs. self-reported total energy intake by Snap-N-Send and SenseWear Armbands (SWA) and microtechnology unit derived Metabolic Power.

Measure of TEE	**Criterion ($Kcal.day^{-1}$)**	**Practical ($Kcal.day^{-1}$)**	**Standardised Mean Bias**	**Typical Estimate of Error**	***P* value**
Pre-Season	16.51 ± 2.67	16.72 ± 1.31	0.13 [-0.64 to 0.91] *Trivial*	1.86 [0.49 to 2.23] *Very Large*	0.833
In-Season	14.94 ± 2.53	15.45 ± 1.43	0.24 [-0.32 to 0.80] *Small*	0.91 [0.35 to 7.73] *Large*	0.464
Pre-Season	16.51 ± 2.67	13.00 ± 2.08	-1.43 [-2.35 to -0.51] *Large*	1.57 [0.45 to 2.79] *Very Large*	0.017
In-Season	14.94 ± 2.53	12.76 ± 2.22	-0.77 [-1.39 to -0.16] *Moderate*	1.11 [0.41 to 2.61] *Very Large*	0.021